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Planarian activity differences when maintained in water pre-treated with magnetic fields: a nonlinear effect

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There have been multiple claims that exposing water to a static magnetic field affects its properties which influence living systems. To test this hypothesis, planarian subsequent to dissection were maintained in spring water that had been previously exposed for only one day to one of three (16, 160, or 1,600 G) intensity static magnetic fields or to a reference condition. Although there was no significant difference in regeneration rates over the subsequent seven-day period, there was a statistically significant nonlinear effect for planarian mobility and diffusion rates. Both mobility rates and diffusion velocity of a liquid within the water that had been exposed to the 16 G field was about twice that for water exposed to the other intensities. These results imply that nonlinear biophysical effects may emerge under specific conditions of intensity ranges for particular volumes of water.

Keywords Magnetic field, Planarian, Diffusion velocity, Mobility, Nonlinear effects

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INTRODUCTION

Intracellular water comprises approximately 80% of all living cells (Cooke and Kuntz, 1974). A fourth of intracellular water is bound to intracellular components with exchange rates in the order of a picosecond. Water is a highly polymerized molecule that displays localized, brief alterations in structure, fluidity, "memory," and adaptation to external forces. Preparata (1995) indicated that liquid water consists of two compartments within which all molecules either synchronously oscillate or oscillate randomly. The width of coherence domains is in the order of micrometers and at room temperature accounts for about 40% of the medium.

A second physical property of matter that has been present since abiogenesis (Cole and Graf, 1974) is magnetic fields. Intrinsic magnetic fields associated with moving electric charges are generated within cells and biological systems. Externally applied static magnetic fields can exert Lorenz forces on ion motions while externally applied time-varying fields exert influence through a plethora of potential mechanisms that range from Faraday induction to resonance. Special molecules, such as magnetite, may enhance punctate (multiple, very local) amplification. Because of the pervasive penetrability of magnetic fields, living systems are immersed in their multipotent effects.

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The subtle changes in ion movement, and hence current within tissue, have been shown to affect regeneration and tissue repair. Becker (1961) reported regeneration of limbs within salamanders following the appropriately applied polarity of direct current. Selected bone repair has also been shown with time-varying fields (Becker and Seldin, 1985). Mild disorganizations of cellular arrangements in the hippocampal formation of rats exposed continuously during their prenatal development to weak (50 nT) complex physiologically-patterned magnetic fields (St–Pierre et al., 2008) suggest that biological systems during organization may be sensitive to geomagnetic-variation level intensity fields.

In the present study, we examined the possibility that direct effects of a static magnetic field upon the water within which (after removal of the field) planarian live would influence their mobility and regeneration. These aquatic flatworms display the remarkable ability to regenerate regardless of the segmentation plane at which the injury occurred (Newmark and Alvarado, 2001). Planarian are the simplest organisms to display cerebral ganglia (Alvarado and Newmark, 1999), a caudal-rostral biopotential (Brondsted, 1954), and sensitivities to weak static magnetic fields (Brown, 1962).

Planarian worms were considered an optimal animal model to discern if *a priori* magnetic field treatment of water could affect their subsequent aqueous mobility and rate of regeneration. Application of a bar magnet to a container of spring water has been claimed to affect the oxidation/reduction rates of solvents or the proportion of oxygen availability to these reactions. Magnetically-treated aerated water increased saturation of suspended particles (Ostsuka and Ozeki, 2005) conductivity and pH (Al-Qahanti, 1966) through presumed strengthening of hydrogen bonds (Ghauri and Ansari, 2006). These effects do not occur with distilled water. Here, we present data that pre-exposure of spring water to various intensity static magnetic fields before it became the planarians' habitat resulted in a nonlinear, intensity-dependent alteration in their mobility and the diffusion rates of a solute.

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MATERIALS AND METHODS

Planarian

Planarian (*Dugesia tigrina*) were obtained from Carolina Biological Supplies and were allowed to proliferate in the laboratory for 11 months prior to the experiments. They were maintained in colonies of approximately 100 worms per 300 cc of spring water (Feversham, Grey County, Ontario) in glass (spice) jars. The ion content of the water in ppm was: HCO3 270, Ca 71, Mg 25, SO4 5.9, Cl 2.7, NO3 2.6, and Na 1. The worms were fed raw beef liver weekly. There was no evidence of mortality. A total of 168 worms were used in this study.

Equipment and Exposures

Magnetic treatment involved exposing spring water in glass containers at various distances from a Raytheon horseshoe magnet with a width of 5.2 cm between the poles; the area for each was 13 cm^2. The glass spice jars (4.3 cm in diameter) containing 25 cc of spring water were placed at distances so the intensity of the averaged magnetic field strength was 1600 G, 160 G, and 16 G as measured by a model GM1A gaussmeter from Applied Magnetics Laboratory Inc. The fourth position was at a distance where there the field strength was equal to the background intensity when the magnet was not present [However, a MEDA FVM-400 Vector Magnetometer indicated the resultant field was 80 μT in this position]. Consequently, for any given experiment there were 8 containers. There were a total of 7 separate experiments. To accommodate environmental variance the poles

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of the magnets were reversed for every second experimental trial and were treated as a covariate. Water was exposed once, for 24 h.

The exposure areas were along a temporary wall in the laboratory. The background static field was attenuated by the metal within the barrier such that, according to the MEDA flux magnetometer, the resultant field strengths in the exposure areas (without the presence of the horseshoe magnet) ranged from 13 to 16 μT or about one-third of the typical average strength (45 μT) within this region. At a distance of 1 m from the wall towards the middle of the room the value was about 45 μT.

Procedures

Planarian were decapitated with a scalpel blade while placed on ice at the prepharynx and introduced immediately to the treated water containers. From this point there was no further exposure of the water containers to the magnetic fields. Over the following six days, planarian regeneration was examined under a dissection microscope. The presence or absence of convex cephalization, photoreceptors, and auricles were noted. Progressive development of sensory organs was ranked according to Figure 1.

Within 24 h after decapitation and for 7 days, planarian were placed individually in a flat container with floor dimensions of 21 cm × 21 cm with 0.5 × 0.5 cm grids. The open field contained 5 mm deep of spring water (untreated) that was refreshed daily. A light homogenizer surrounded the open field to enhance light diffusion and discourage phototaxis. The worms were removed from their environments with a pipette. Planarian velocity was assessed by counting the numbers of grid lines crossed per 3 min period and converting this value to mm/min. After removal from the field the planarian were returned to their home environment containing the treated water.

The water exposed to the different intensities and polarity magnetic fields were tested for diffusivity. A section of a plastic cover for food was cut to form a trough with a linear depression 3 mm wide and 10 mm long (30 mm^2). It was filled with .3 cc of water from each treatment in counterbalanced order over several days. A droplet (6 μL) of India ink (dilution 15:1 water to ink) was introduced to the surface area by a 1 cc (25 G needle) syringe.

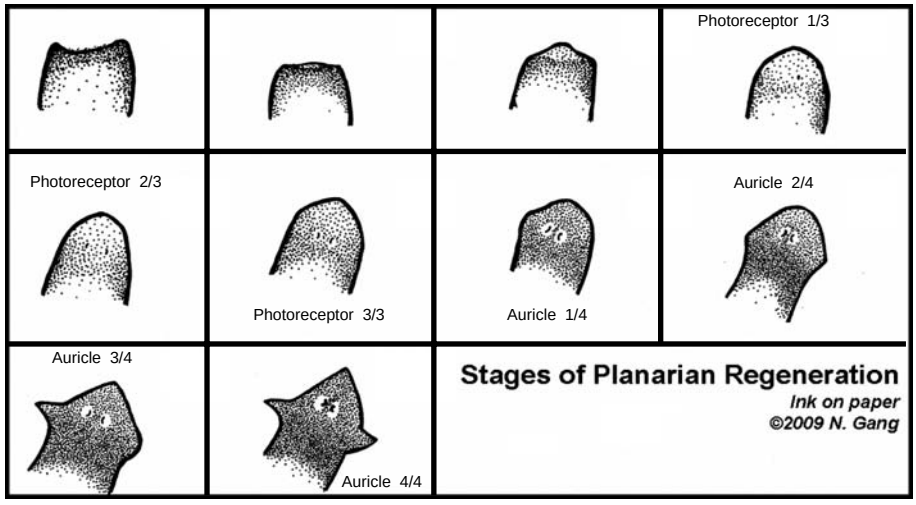

FIGURE 1 Stages of planarian regeneration that were employed as references for ratings for the present study.

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The numbers of measures (taken at 5 min intervals for over several weeks) for the different intensities were: 1600 (n = 136), 160 (n = 130), 16 (n = 131), and control (n = 64). The time required for diffusion to occur over the 30 mm^2 was recorded and called diffusion velocity in mm/s. Temperature within the experimental room was + /− 0.5 deg of 21°C. Although the magnetic field conditions for both the planarian velocity and diffusion of the ink were known to the first author, the effects were conspicuous by casual observation by visitors in the laboratory.

RESULTS

There were no statistically significant changes in the rate of regeneration for the planarian that had been exposed to the various intensities of magnetic field-treated waters compared to controls. However, there was a statistically significant [$F(2,39) = 3.52$, $p < .05$] difference between the velocity of planarian movements, as can be seen in Figure 2. Covariance for ambient geomagnetic activity (A-index) at the time of testing enhanced the effect [$F(2,38) = 5.52$, $p < .01$; eta-squared = 17%]. Post hoc analysis indicated that the planarian regenerating in the water that had been exposed to the 16 G magnetic field before the planarian were introduced showed significantly more mobility (by almost a factor of 2) compared to those that had lived in the water that had been exposed to the 1600 G field or to no field.

The diffusion velocity of ink in the water that had been exposed to the various intensities of the fields also showed the greatest enhancement for the 16 G treatment compared to the 1,600 G and control (no field) treatments (Figure 3). There was a significant [$F(3,453) = 13.43$, $p < .001$] difference in velocities of ink diffusion within the water extracted from the various jars that had been exposed to one of the four intensities. The correlation between the diffusion velocity and movements of the planarian exposed to the four intensity magnetic fields was 0.96.

Because of the modulating role of ambient geomagnetic activity on the mobility measures, Spearman rho correlations (to minimize outlier effects) were completed between A-index values and various growth measurements for planarian living in the different treatments. The correlations (rhos > 0.45, $p < .05$) between the control, 16 G, 160 G, and 1,600 G intensities and A-index values for auricular development

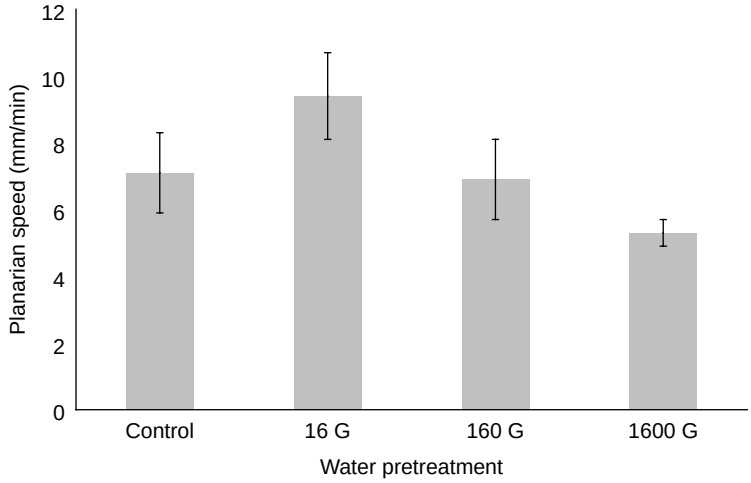

FIGURE 2 Average planarian velocity (mm/min) as a function of the intensity of the magnetic field to which the habitat water had been exposed for 24 h before their introduction and maintenance for 5 days. Testing occurred in fresh spring water.

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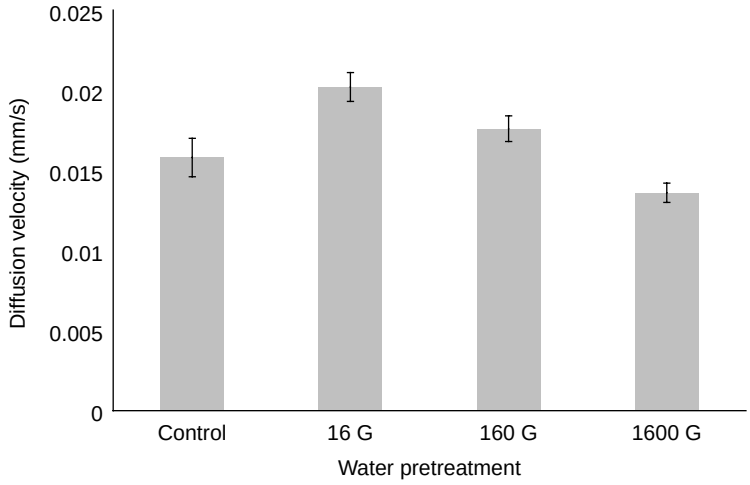

FIGURE 3 Diffusion velocity (mm/s) of a drop of ink in water that had been exposed to one of the four intensities of magnetic fields.

were −0.54, −0.27, −0.44, and −0.62, respectively. For the photoreceptors the correlations were 0.12, 0.46, 0.61, and 0.21, respectively. For comparison, there were no significant correlations between mobility and photoreceptor development (rho = 0.20) and mobility and auricle development (rho = 0.27) for all groups of planarian combined.

DISCUSSION

The results of this study suggest that a single, 24 h exposure of 25 cc of water to a magnetic field strength of 16 G before it became the primary habitat affected the velocity of movement of planarian for at least seven days. This conclusion is based upon the statistically significant increase in mobility of the planarian that was about twice the value compared to planarian whose habitat was obtained from water that had been exposed to normal (local) geomagnetic field intensities or the higher intensities of 160 G and 1,600 G. However none of the water environments exposed to the various magnetic field intensities affected rates of regeneration in any statistically significant manner.

Regeneration rates might be sensitive to weaker magnetic fields. This was suggested by the consistent negative correlations between geomagnetic activity and auricular development (which explained about 25% of the shared variance) regardless of the static field intensity to which the water had been exposed before the planarian was introduced. That the local static field could modulate this effect was indicated by significant positive correlations between geomagnetic activity and photoreceptor growth for only planarian that had lived in water that had received the 16 and 160 G fields. Optimal intensities for time-varying magnetic fields superimposed upon static fields are critical for the conditions that promote cyclotron resonance phenomena. The effects of weaker ambient magnetic fields upon planarian regenerating in magnetically treated water should be further investigated.

The strong correlation between the diffusion velocity of water that had been exposed to the different intensities of magnetic fields and the movement of planarian that had resided in these different aqueous environments indicates a physical property within the water itself was induced and maintained after the magnetic fields were removed. That variation of the viscosity of water with magnetic field strengths

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cannot be predicted by the fundamental relationships of physics is a traditional assumption. However, enhanced viscosity ranging from .06–.27% relative to baseline measures within field strengths ranging from 0.5 and 1.5 T have been reported. Fahidy (2002) reported a study that showed diminished viscosity of 3.5% was associated with 370 A/m which is equivalent to 5.9×10^{-4} T or 5.9 G.

If there was a diminished viscosity of water this might explain the enhanced movement of planarian that lived during the subsequent five days to the 16 G-exposed water. Movement was tested in normal spring water which suggests that the enhanced mobility was maintained. What is not clear is the duration of the effects of the 16 G magnetic field on the water. Considering the behavioral observations, this strength was certainly sufficient to produce quantitative changes in planarian activity.

We suggest that the hydronium ion (Decoursey, 2002), with its extra proton may have mediated the changes in diffusion velocity. The energy available within the 0.3 cc of the test volume for diffusion experiments from a 1.6×10^{-3} T (1.6 G) magnetic field, according to the relation $J = [B^2/(2*4\pi*\mu)]*m^3$ (volume), where B is the strength of the field and μ is magnetic permeability, would be 3×10^{-7} J. Because the concentration of hydronium molecules is about 40 nM compared to the 110 M of H^+ within water (Decoursey, 2002) a total of about 0.75×10^{13} H_3O^+ molecules would be contained in 0.3 cc. This means there would be about 4×10^{-20} J per molecule which is within the range of energies for chemical bonds and may be a fundamental quantum value for physical chemical interactions in biological systems (Persinger, 2008).

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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